Effects of an intermediate scale in SUSY grand unification

N. G. Deshpande[a] *, B. Dutta[a] *, and E. Keith[b] †

[a]Institute of Theoretical Science, University of Oregon, Eugene, OR 97403, USA

[b] Department of Physics, University of California, Riverside, CA 92521, USA

OITS-606

UCRHEP-T167

We discuss the production of lepton flavor violation and EDMs and the viability of the $b-\tau$ unification hypothesis in SUSY grand unification with an intermediate gauge symmetry breaking scale.

Supersymmetric grand unified theories (GUTs) with intermediate gauge symmetry breaking scales are attractive because they resolve a few longstanding problems and possess some desirable phenomenological features. For example, in models where the intermediate breaking scale $M_I \sim 10^{10} - 10^{12}$ GeV, one can naturally get a neutrino mass in the interesting range of $\sim 3-10$ eV, which could serve as hot dark matter to explain the observed large scale structure formation of the universe. In models without an intermediate gauge symmetry, in principle one could produce a tau-neutrino Majorana mass that is much less than the GUT breaking scale as for example via non-renormalizable operators involving Higgs in the SO(10) $\overline{16}$ representation or a small and carefully chosen Yukawa coupling to a $\overline{126}$ field. However, this would suffer from the further problem of abandoning $b-\tau$ Yukawa coupling unification except possibly in the case of high $\tan\beta$ [1]. The window $\sim 10^{10} - 10^{12}$ GeV is also of the right size for a hypothetical PQ-symmetry to be broken so as to solve the strong CP problem without creating phenomenological or cosmological problems. Models which allow even lower intermediate gauge symmetry breaking scales [2,3] e.g. $M_I \sim 1$ TeV are also interesting since they predict relatively light new gauge fields, as for example SU$(2)_R$ charged gauge bosons W_R. A further motivation for studying GUTs with intermediate gauge symmetry breaking scales is that some scenarios may allow lower values of α_s as preferred by some experiments.

In this talk based on Ref. [4–6], we will discuss lepton flavor violation, the production of an electron and neutron electrec dipole moment (EDM), and the viability of the GUT scale $b-\tau$ unification hypothesis in GUTs in which the T_{3R} and T_{B-L} generators are unbroken above M_I. We will always assume that supersymmetry is broken via soft breaking terms introduced at a super high scale. We shall assume that the soft breaking terms at the high scale at which they are introduced are flavor blind and CP invariant. As examples, in Ref. [4–6] we have used four different models with intermediate gauge symmetry breaking scales.

It has recently been pointed out [7] that significant lepton flavor violation, as well a electron and neutron EDMs, can arise in supersymmetric (SUSY) grand unified theories. The origin of this flavor violation resides in the largeness of the top Yukawa coupling and the assumption that supersymmetry is broken by flavor uniform soft breaking terms communicated to the visible sector by gravity at a scale M_X. Assuming that M_X is the reduced Planck scale which is much greater than M_G, renormalization effects cause the third generation multiplet of squarks and sleptons which belong to the same multiplet as the top in the grand unified theory (GUT) to become lighter than those of the first two generations. The slepton and the charged lepton mass matrices can no longer be simultaneously diagonalized thus inducing lepton flavor violation through a suppression of the GIM mechanism in the slepton sector. This effect is more pronounced in SO(10) models than in SU(5) where the left-

*Supported by DOE grant DE-FG06-854ER 40224.
†Supported by DOE grant DE-FG02-94ER 40837.

handed slepton mass matrices remain degenerate. The evolution of soft terms from M_X to M_G causes these flavor violations, which disappear when $M_X = M_G$. Here, we explore another class of theories which are SUSY SO(10) GUTs which break down to an intermediate gauge group G_I before being broken to the Standard Model (SM) gauge group at the scale M_I. In this class of theories, even if $M_X = M_G$, lepton flavor violation arises due to the effect of the third generation neutrino Yukawa coupling on the evolution of the soft leptonic terms from the grand unification scale to the intermediate scale. Depending on the location of the intermediate scale M_I and the size of the top Yukawa coupling at M_G, these rates can be within one order of magnitude of the current experimental limit. Our results also indicate that if $M_X > M_G$ in SUSY SO(10) models with an intermediate scale, the predicted rates of lepton violating processes are further enhanced. We will concentrate on the decay $\mu \to e\gamma$ as an example since experimentally it is likely to be the most viable.

With G_I=SU(2)$_L\times$SU(2)$_R\times$SU(4)$_C$ ($\{2_L\, 2_R\, 4_C\}$), the quarks and leptons are unified. Hence, the τ-neutrino Yukawa coupling is the same as the top Yukawa coupling. Through the renormalization group equations (RGEs), the effect of the large τ-neutrino Yukawa coupling is to make the third generation sleptons lighter than the first two generations, thus mitigating the GIM cancellation in one-loop leptonic flavor changing processes involving virtual sleptons. Although the quarks and leptons are not unified beneath the GUT scale when G_I=SU(2)$_L\times$SU(2)$_R\times$U(1)$_{B-L}\times$SU(3)$_c$ ($\{2_L\, 2_R\, 1_{B-L}\, 3_c\}$), the same effect is produced from the assumption that the top quark Yukawa coupling is equal to the τ-neutrino Yukawa coupling at the GUT scale. In Ref. [4,5], one can see that such models can easily predict rates of lepton flavor violation that are within an order of magnitude beneath experimtal limits and can sometimes even put limits on the allowable parameter space.

When we calculate the EDM of the electron the above stated principle applies, but we must also consider the phases at the gaugino-slepton-lepton vertices. Likewise, to generate the EDM for the neutron one needs the third generation down squark to be lighter than those of the other two generations, which occurs due to the large top Yukawa coupling, and new phases at the gaugino-squark-quark vertices. In fact, whenever there is an intermediate scale, irrespective of G_I such phases are generated. The reason for this is that right-handed quarks or leptons are unified in a multiplet in a given generation. The superpotential for an intermediate gauge symmetry breaking model can be written (when $G_I = \{2_L\, 2_R\, 4_C\}$) as $W_Y = \lambda_{\mathbf{F_u}} F \Phi_2 \bar{F} + \lambda_{\mathbf{F_d}} F \Phi_1 \bar{F}$, where F and $\bar{F}$ are the superfields containing the standard model fermion fields and transform as $(2,1,4)$ and $(1,2,\bar{4})$ respectively and we have suppressed the generation and gauge group indices. We choose to work in a basis where $\lambda_{\mathbf{F_u}}$ is diagonal in which W_Y can be expressed as $W_Y = F\bar{\lambda}_{\mathbf{F_u}}\bar{F}\Phi_2 + F\mathbf{U}^*\bar{\lambda}_{\mathbf{F_d}}\mathbf{U}^\dagger\bar{F}\Phi_1$. The matrix $\mathbf{U}$ is a general 3×3 unitary matrix with 3 angles and 6 phases. It can be written as $\mathbf{U} = \mathbf{S'}^*\mathbf{V}\mathbf{S}$, where $\mathbf{V}$ is the CKM matrix and $\mathbf{S}$ and $\mathbf{S'}$ are diagonal phase matrices. At the weak scale, we have the Yukawa terms:

$$\begin{aligned} W_{\mathrm{MSSM}} &= Q\bar{\lambda}_{\mathbf{u}}\mathbf{U^c}H_2 + Q\mathbf{V}^*\bar{\lambda}_{\mathbf{d}}\mathbf{S}^2\mathbf{V}^\dagger D^c H_1 \\ &+ E^c\mathbf{V}_{\mathbf{I}}^*\bar{\lambda}_{\mathbf{L}}\mathbf{S}^2\mathbf{V}_{\mathbf{I}}^\dagger L H_1 \,, \end{aligned} \tag{1}$$

where the ability to reduce the number of phases by redefinition of fields has been taken advantage of to the fullest extent possible, $\mathbf{S}^2 \equiv \mathrm{Diag.}\left(\mathrm{e}^{i\phi_d}, \mathrm{e}^{i\phi_s}, 1\right)$ is a diagonal phase matrix with two independent phases, and $\mathbf{V_I}$ is the CKM matrix at the scale M_I. It is not possible to do a superfield rotation on D^c or L to remove the right handed angle since at M_I the third diagonal element of the scalar mass matrices $\mathbf{m_D^2}$ and $\mathbf{m_L^2}$ develop differently from the other two diagonal elements due to large top Yukawa coupling RGE effects. When $G_I = \{2_L\, 2_R\, 1_{B-L}\, 3_c\}$, the additional CKM-like phases will be generated in exactly the same way as described above. Results for specific examples can be found in Ref. [6], where one can see that highly significant EDMs can be produced by the physics of the intermediate scale gauge symmetry.

Now we discuss the viability of $b-\tau$ unification hypothesis. In this talk, we will concentrate

on the following two models: (1) the model of Ref. [5] which has G_I=SU(2)$_L\times$SU(2)$_R\times$SU(4)$_C$ with $M_G \approx M_{\rm string}$ and $M_I \sim 10^{12}$ GeV, and (2) the model of Ref. [2] which has G_I=SU(2)$_L\times$SU(2)$_R\times$U(1)$_{B-L}\times$SU(3)$_C$ and allows M_I to have any value between the TeV scale and M_G. The value for $m_b^{\rm pole}$ from the existing data is $m_b^{\rm pole}$=4.75$\pm$ .05, and we use $m_\tau = 1.777$ GeV. The predicted m_b mass in these intermediate scale models mainly depend on 3 factors: the value of λ_{t_G}, $\alpha_s(M_Z)$ and the location of the intermediate scale M_I. Using larger values of λ_{t_G} of course lowers the m_b mass, while using larger values of α_s increases it. For these models at the scale M_G, we use the maximum perturbative value for the top Yukawa coupling which is about 3.54. For the model of Ref. [5], since leptons and down quarks are unified in the same multiplet at the intermediate scales we have $\lambda_b = \lambda_\tau \neq \lambda_t = \lambda_{\nu_\tau}$ for the low $\tan\beta$ version of that model. We find $m_b^{\rm pole} = 4.78$ GeV. For the large $\tan\beta$ version, we have $\lambda_t = \lambda_b = \lambda_\tau = \lambda_{\nu_\tau}$ instead, and find $m_b^{\rm pole} = 4.80$ GeV. We find that the model of Ref. [5] is able to provide very reasonable b-quark mass predictions since α_s is of moderate values and since down to the scale M_I the relation $\lambda_b = \lambda_\tau$ exists intact. For the model of Ref. [2] with $\lambda_t = \lambda_b = \lambda_\tau = \lambda_{\nu_\tau}$ at M_G, in Fig. 2(a) of Ref. [6] we plot the $m_b^{\rm pole}$ mass as a function of M_I since the intermediate gauge symmetry breaking scale in that model can lie anywhere between the weak scale and the GUT scale. We find that that the b-quark mass at first increases as the intermediate gauge symmetry breaking scale moves away from the GUT scale. But, it then reaches a peak value when the intermediate scale is about 10^8 GeV, and then for M_I less than that scale it decreases. The reason for this behavior can be found in the RGEs for λ_b and λ_τ. The RGE for λ_b feels the influence of the large top Yukawa coupling while λ_τ instead feels the influence of the τ neutrino coupling. Though the magnitude of the top and the τ neutrino couplings are same at the GUT scale, the τ-neutrino coupling decreases faster than the top Yukawa coupling and reaches its fixed point sooner. If the Intermediate breaking scale is decreased $\lambda_b(M_I)$ would also decrease, however $\lambda_\tau(M_I)$ would not decrease as much. So, effectively the mass of m_b decreases, since m_b mass depends on the ratio of λ_b to λ_τ. We further note that the interesting values for the intermediate gauge symmetry breaking scale $M_I \sim 1$ TeV and $M_I \sim 10^{12}$ GeV can both give good values for the b-quark mass. Effects of this low intermediate scale could be observed in the future colliders. In Fig. 2(b) of Ref. [6], we assume the possibility of the model of Ref. [2] allowing a range of values for $\tan\beta$ in order to plot the $m_b^{\rm pole}$ as a function of $\tan\beta$ for the interesting case of $M_I = 10^{12}$ GeV. We see that larger values of $\tan\beta$ are preferred and give very reasonable values for the b-mass. Of course as in Ref. [8], one could purposefully construct models with G_I=SU(2)$_L\times$SU(2)$_R\times$U(1)$_{B-L}\times$SU(3)$_C$ that have $M_I \sim 10^{12}$ GeV and lower values for α_s so as to improve the b-quark mass prediction for low values of $\tan\beta$.

REFERENCES

1. F. Vissani and A. Y. Smirnov, Physics Letters **B341**, 173 (1994); A. Brignole, H. Murayama, and R. Rattazzi, Physics Letters **B335**, 345 (1994).
2. N. G. Deshpande, E. Keith and T. G. Rizzo, Phys. Rev. Lett. **70**, 3189, (1993).
3. E. Ma, Phys. Rev. **D51**, 236, (1995).
4. N.G. Deshpande, B. Dutta, and E. Keith, Phys. Rev. **D54**, R730, (1996).
5. N.G. Deshpande, B. Dutta, and E. Keith, hep-ph/9604236, (to appear in Phys. Lett. **B**), (1996).
6. N.G. Deshpande, B. Dutta, and E. Keith, hep-ph/9605386, (to appear in Phys. Lett. **B**), (1996).
7. R. Barbieri and L. J. Hall, Phys. Lett. **B338** 212, (1994); S. Dimopoulos and L. J. Hall, Phys. Lett. **B344**, 185 (1995); R. Barbieri, L. J. Hall, and A. Strumia, Nucl. Phys **B445**, 219, (1995).
8. B. Brahmachari and R. N. Mohapatra, Phys. Lett. **B357**, 566 (1995).